PRINCETON UNIVERSITY

DEPARTMENT OF AEROSPACE AND MECHANICAL SCIENCES

FIRST ANNUAL REPORT ON

FUNDAMENTAL AND APPLIED RESEARCH ON CORE ENGINE/COMBUSTION NOISE OF AIRCRAFT ENGINES

by

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NASA Grant NGR 31-001-307

JULY 1974

Transmitted by

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ABSTRACT

Some results of a study of the importance of geometrical features of the combustor to combustion roughness and resulting noise are presented. Comparison is made among a perforated can flame holder, a plane slotted flame holder and a plane slotted flame holder which introduces two counter swirling streams. The latter is found to permit the most stable, quiet combustion. Crosscorrelations between the time derivative of chamber pressure fluctuations and far field noise are found to be stronger than between the far field noise and the direct chamber pressure signal. Temperature fluctuations in the combustor nozzle are also found to have a reasonably strong crosscorrelation with far field sound. Indications are given of areas where further work is planned relating to these findings.

Results obtained in a study aimed at reducing combustion noise are reported, including some preliminary findings relating to U.S. Patent No. 3,620,013. It is found that noise from a propane torch is substantially reduced as a result of inserting wires across the air induction nozzle. The reduction in noise is found to be due to the reduction in induced air flow, resulting in an extended, less intense, quieter flame. Further studies of this and related phenomena are being pursued.

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1.0 INTRODUCTION AND GENERAL DESCRIPTION OF THE RESEARCH PROGRAM

Earlier studies of the relative importance of combustion as a source of noise in jet engines[1,2] revealed that the intensity of combustion roughness, which generates noise, was affected by the type of flame holder and the air/fuel mixture used, as well as on the flow rate through the combustor. Approximate relationships were derived to predict the far field noise due to the combustor pressure oscillations, and it was found experimentally, that there was a correlation between pressure and temperature fluctuations in the combustor and far field noise. The present research is a continuation of that earlier work.

In the present work we are studying, over a broader operating range, the relative importance of

(a) burning characteristics of the fuel; how burning rate, diffusion rate of the fuel into the air, intensity of combustion, flame distribution and flame roughness affect the noise generated.

(b) geometrical features of the combustor; effect of fuel injector configuration and type, the method of air admission -- whether swirling, highly turbulent or smooth, stratification of air and fuel and insertion of obstacles to modify the flame.

In addition to the above objectives, we are seeking to develop better means of measuring the important parameters, such as pressure, temperature and velocity fluctuations in the combustor and exhaust flow, and to improve analytical schemes to predict the contribution to far field noise made by these internal sources.

This report presents some results obtained with several flame holder geometries in which fuel/air mixing was varied by the use of a perforated can burner, a plane, slotted flame holder and a plane slotted flame holder with turning vanes to introduce swirl. Some further interpretations and correlations of internal pressure with far field sound are included. In addition, results of temperature fluctuation measurements and their correlation with far field sound are presented. Preliminary results of a study of the effect on a flame due to transverse wires across the throat of a propane torch nozzle are included, with documentation of the tests performed.

2.0 COMBUSTION ROUGHNESS STUDIES

The emphasis during the past year has been on obtaining experimental data relating to the two main objectives stated in Section 1. The facility used for these experiments is the same one described in references 1 and 2, with modifications in the combustor, operating procedures and data analysis methods as described in connection with the studies performed.

2.1 Flame Holder Geometry Effects

2.1.1 Details of Combustors

Figure 1 is a schematic of the combustor apparatus showing the perforated can and the plane slotted, swirl vane flame holders. The perforated can was used previously,[1,2] and simply consists of a 2.5" O.D., 13.5" long can concentrically placed within the 3" I.D. main tube with 0.40" diameter perforations beginning about 3.25" from the closed front end where the fuel is injected. Isooctane fuel is injected as a conical spray. Hydrogen and air are injected at the gap of a spark plug which ignites the gaseous mixture which in turn ignites the spray combustion. Recirculation of the secondary air (there is no primary air) which enters through the perforations serves to stabilize the flame reasonably well.

The second configuration shown in Fig. 1 has both primary and secondary air. Primary air enters through the outer 0.2" periphery of the 1.3" diameter inner ring. Fuel is injected through a hole at the center of this inner ring. A second ring, 2.375" O.D., fits around this inner cylinder. In the configuration shown, the inner ring has vanes set at about 60° to the flow axis, which create a clockwise swirl when looking downstream. The outer ring has similar swirl vanes set to generate a counter clockwise swirl. A 2.5" diameter sleeve fits over this assembly which is mounted concentrically within the 3" diameter main combustor tube. The fuel/air mixture is ignited as with the perforated can, but the flame is now stabilized only by the small scale recirculation due to the flow over the sharp edges of the vanes.

A third configuration, not shown in Fig. 1, is geometrically similar to the swirl vane assembly, except that the vanes are simply slotted, and do not cause a swirl. This flame holder was intended to give about the same air flow distribution and similar local recirculation flows around the vanes but without the swirl generated by the above described assembly. With these three flame holders, we can compare the effect of flow distribution, with and without swirl in one of the two flow distributions, to determine whether the unsteady nature of the combustion region which is responsible for the noise generation, can be significantly altered by these changes.

2.1.2 Roughness Characteristics of Combustors

Figure 2 shows the roughness level of pressure fluctuations in the three combustors for a range of mass flow rates through the system. At the low end of the range of mass flow rates, the can combustor exhibits very rough, intermittent burning, almost to the extent that the flame is blown off. As the flow rate is increased slightly, the combustion becomes smoother in the can combustor, so that at the upper end of the range shown, it has smoother burning than is found in the case with the plane, slotted flame holder. Over this entire range of flow conditions, the plane slotted flame holder with swirl vanes exhibits the smoothest burning of the three. To an observer standing near the combustor, the difference between the swirling combustor noise and the can combustor noise is dramatically different.

Detailed acoustic far field measurements have not been obtained for each of these combustor configurations to date. The spectral content of the flame roughness has, however, been examined, and power spectral density distributions are included here for comparisons.

Figures 3 through 5 show the power spectral density distributions for the three combustor configurations, for the highest flow rate condition shown on Fig. 2. Figure 3 is for the can combustor, and exhibits very strong oscillations at low frequencies. This low frequency rumble was more pronounced at lower flow rates with this combustor, especially at the lowest condition shown on Fig. 2. At that lowest condition, the 164 dB bursts would last for several seconds, then the oscillation would drop to a level of about 145 dB for a second or two, followed by another loud burst, and so on. Clearly, this kind of intermittent, rough burning is not desirable in an aircraft engine combustor. The relatively smoother burning in the other two cases at this low flow rate by comparison with the rough burning case illustrate the big improvements that are possible in terms of noise levels when appropriate changes are made in combustor designs.

Comparisons of Figs. 3, 4, and 5 reveal at least two strong spectral peaks at frequencies above 100 Hz. In Fig. 3 these peaks are at about 150 and 400 Hz, in Fig. 4 they are at about 350 and 550 Hz and in Fig. 5 they occur at about 300 and 475 Hz. These peaks are probably related to duct resonances excited by the unsteady combustion.[3] More detailed measurements of the conditions in the combustor corresponding to each of these cases is needed to explain why these spectral peaks appear at these particular frequencies at these flow conditions.

It is evident from the results obtained with these three combustors, that swirl in the flow is desirable. The swirling promotes better mixing between the fuel and air, resulting in a

more smoothly burning flame. Not only does this result in less noise outside the combustion region, but it results in more stable combustion over a broader range of operating conditions.

2.2 Far Field Noise Correlation with Chamber Pressure

It was shown earlier[1,2] that there is a strong correlation between the chamber pressure fluctuations and the far field noise, as obtained from real time crosscorrelations. The maximum value obtained for the normalized crosscorrelation coefficient was never more than about 0.7 in spite of the fact that the dominant frequencies in the combustor pressure spectrum also appeared in the far field noise spectrum. One point was noted. In each case, the higher frequency components were relatively stronger in the far field than in the combustor spectrum. This was attributed to the fact that high frequency fluctuations are more efficient sources of noise than are low frequency fluctuations.

This is true, and the reason it is so is that the noise produced is proportional to the time rate of change of velocity of the source, while the velocity at the exit plane is directly related to the chamber pressure. Therefore, a more meaningful correlation is obtained by crosscorrelating the far field sound with the time derivative of the chamber pressure fluctuation. Taking the time derivative of a harmonic function has the effect of multiplying by the angular velocity, thus giving larger contributions at high frequencies, as was observed in experiments. This may be seen in the following.

The far field sound due to the mass flow fluctuation at the nozzle exit plane is, following Curle[4]

$$p_f' \sim \oint_S \frac{\partial}{\partial t}(\rho u)_{exit} \cdot dS \tag{1}$$

and

$$\frac{\partial (\rho u)_{exit}}{\partial t} \sim \frac{\partial p_c}{\partial t} \tag{2}$$

where sub f denotes far field, and sub c the chamber.

This second expression is most accurate for incompressible quasi-steady flow. As compressibility effects become important, the fluctuations in temperature must be incorporated into the analysis. We have examined the effect of temperature fluctuations, as described in the next section. First, however, it is of interest to examine the pressure effect alone.

Figure 6 shows the function obtained by crosscorrelating the time derivative of the chamber pressure with the far field sound, and Fig. 7 shows a similar trace for which the chamber pressure itself was crosscorrelated with the far field sound. Since both are dominated by the 170 Hz narrow band sound, there is little difference between them. Close examination reveals that Fig. 6 has its peak at about 44 msec while Fig. 7 has its peak at about 48 msec. The 44 msec corresponds to the travel time to the far field microphone, 50 ft away. The 48 msec is equivalent to the travel time to 50 ft plus about half a wave length of the dominant signal (its peak is on the negative side while the first has a positive peak) corresponding to a 180° phase shift. Other similar experiments reveal peaks at times close to the correct delay but never as exactly at the correct delay as when the time derivative of the pressure is crosscorrelated with the far field sound. When the normalized crosscorrelation coefficient is obtained, the value for the case in Fig. 6 is approximately 1, that for Fig. 7 is 0.94, again emphasizing the closer correspondence between the far field sound and the time derivative of the chamber pressure than between the far field sound and the chamber pressure directly.

2.3 Temperature Fluctuation Effects

It was pointed out in the previous section that in compressible flows, the temperature fluctuation would enter as a parameter affecting noise generation. To obtain meaningful measurements of temperature fluctuations in the combustion gases is considerably more difficult than to obtain pressure fluctuations, as reported earlier.[1] The basic reason for the greater difficulty is the fact that the temperature probe must be immersed in the hot, reacting flow, while the pressure probe can be mounted on the wall where it can be cooled and insulated from the flow.

A hot wire anemometer system in conjunction with a 0.001" diameter platinum wire was used to make the measurements reported herein. The velocity sensitivity of the probe was minimized by maintaining a low probe current (1.5 ma) which kept the wire just above the ambient temperature. Therefore, as the ambient temperature fluctuates, the wire temperature follows, and the anemometer circuit gives an output proportional to wire resistance which is temperature dependent.

Difficulties were encountered due to the high temperature, reactive flow. A metal's strength is generally reduced as its temperature is raised, so although the wire may not melt, it is more easily broken at elevated temperatures. In addition, certain metals such as tungsten catalyze recombination reactions which can result in large errors as the probe temperature is raised, due to additional energy deposition at its surface. Thus, early attempts with tungsten wires yielded unreliable data, and platinum was adopted, in spite of its lower strength.

The maximum temperature recommended for this probe was about 1500°F, which was considerably lower than the mean temperature in previous runs.[1,3] An air/fuel ratio of 70 was adopted for this purpose, which should give a mean temperature of about 1090°F, in the nozzle, but since hot spots can occur in such a system, this seemed a safe condition at which to operate.

The probe used for the temperature measurements was a Thermo Systems Model 1226 High Temperature probe with a 0.001" diameter platinum wire. It was used in conjunction with a TSI Model 1050 Anemometer. The probe was inserted through the nozzle wall so that the wire was held at the duct centerline about 1.25 in. upstream of the nozzle exit. The combustor can configuration, Fig. 1, and a 2" diameter nozzle were used in these experiments.

2.3.1 Spectrum and Level of Temperature Fluctuations

Figure 8 shows the power spectral density of the nozzle temperature fluctuations. A very low frequency fluctuation is dominant with the first peak at 5 Hz, which is the lower limit of the spectral analysis. Relative peaks next occur at 125 and 165 Hz, with a subsequent intensity decrease to the instrumentation noise levels. Figure 9 shows the corresponding far field noise spectrum which exhibits the 165 Hz peak, but does not exhibit the strong low frequency content seen in the temperature spectrum; instead it shows approximate higher harmonics of the 165 Hz peak. The power spectrum of the temperature signal with low frequencies suppressed by a 100 Hz high pass filter is shown in Fig. 10. The 165 Hz peak is now dominant, with another relative peak at 330 Hz. At frequencies above that peak, the noise level of the electronics is dominant over any temperature signals. This may be expected, since the thermal time constant of the wire under these operating conditions is about 2.5 msec, having the effect of filtering out frequencies above about 400 Hz. Either the circuitry does not compensate for this decrease of response with increased frequency, or there is negligible fluctuation in temperature above this frequency. Further experiments with smaller wires are required and planned to explore this further.

The absolute, rms level of temperature fluctuation in the 125-160 Hz, 1/3 octave band was measured to be about 12.5 Fahrenheit degrees, or a little more than 1% of the mean temperature. The overall rms temperature fluctuation in the frequency range from 22 Hz to 22 kHz was measured to be about 20% of the mean temperature, with peak to peak variation considerably higher. This large temperature fluctuation level appears to be somewhat characteristic of jet engine combustors, as evidenced by recent measurements, in which rms temperature fluctuations of several hundred degrees have been measured downstream of the combustor in engine tests.[5] The results presented here do not show a strong relationship between this temperature unsteadiness and noise possibly due to inadequate measurements. Further studies with more refined instrumentation are required to establish its relative importance.

2.3.2 Crosscorrelations of Temperature Fluctuations and Far Field Sound

Figure 11 shows the cross spectral density of the nozzle temperature fluctuation and the far field sound, for each signal taken directly as recorded. The dominant low frequencies noted in the individual frequency spectra are evident in this cross spectrum. The normalized crosscorrelation coefficient was found to be 0.05 for this case.

It would seem, on comparing Figs. 8 and 9, that the very low frequency (below 100 Hz) temperature fluctuations do not substantially contribute to the far field noise. A second crosscorrelation between these same two signals was obtained, this time with a 100 Hz highpass filter cutting out the low frequency content of each signal. The resulting cross spectral density is shown in Fig. 12. The normalized crosscorrelation coefficient in this case is 0.276, or more than five times as large as for the unfiltered signal. This higher correlation after filtering out the intense fluctuations at ultra low frequencies illustrates that a simple overall crosscorrelation coefficient is not sufficient information to determine the percentage of far field noise which originated at the source being probed.

It is of interest to note further, that these data in which the normalized temperature-far field crosscorrelation coefficient is 0.276 are the same data for which the normalized pressure time derivative-far field sound crosscorrelation coefficient was $\sim$ 1., as discussed earlier. This implies that the temperature and pressure fluctuations are related, as was verified by direct crosscorrelations. It further tells us that the normalized crosscorrelation coefficient alone is not sufficient information to use to describe the relative importance of various thermodynamic variables in describing the source strength. Before taking the temperature data, it appeared that the time derivative of pressure contained all the necessary information about the source, neglecting compressibility effects. The temperature data has some merits of its own, however, as evidenced by the normalized crosscorrelation coefficient of 0.276. A more complete study of the interrelations of these variables is needed, and how each contributes to the noise must be ascertained. More detailed studies of this are planned.

2.4 Conclusions and Future Plans

It has been demonstrated that geometrical changes in the combustor which affect the flame distribution and method of flame stabilization have a pronounced effect on the flame roughness and associated external noise generation. Of the methods examined to date, counter swirling air streams have been found to produce the smoothest combustion. Further probing with pressure and temperature probes in the combustor to learn more about the mechanisms by which these geometric changes affect the combustion roughness are planned.

It has further been demonstrated that the time derivative of the chamber pressure more strongly crosscorrelates with the far field noise than does the chamber pressure directly. This is expected from theoretical considerations. Temperature fluctuations in the exhaust nozzle of the combustion chamber are also found to have a fairly strong crosscorrelation with the far field sound, and with the chamber pressure fluctuations. Further analysis and diagnostic experiments are needed and planned to separate the importance of each of these thermodynamic properties of the source region for the purpose of completely describing the physical processes responsible for sound generation by a region of unsteady combustion and its exhaust flow.

3.0 REDUCING COMBUSTION ROUGHNESS

There are probably many ways to reduce combustion roughness. One way, as discussed in Section 2, is to alter the flame holder and combustor geometry until an optimum arrangement is found. Assuming, however, that the optimum thus found may not be satisfactory, it may still be of interest to provide other means of damping out oscillations.

It has been found in our research [1,2,3] that the dominant frequencies of rough combustion are related to duct resonance modes, for combustor pressures between 1 and 2 atmospheres absolute. Similar resonant phenomena have been observed in flames by earlier researchers; e.g., "singing flames". A means of suppressing this resonance could be of considerable interest, since it would reduce the dominant noise source.

The results presented in this section document some preliminary studies of an invention which claimed that a rod or rods could be used to cancel the resonant node or nodes developed in a supply tube by a combustible mixture passing through it [6]. Certain aspects relating to the invention, although not all the possible configurations suggested by the invention, were studied to date. The abstract of the disclosure of U.S. Patent No. 3,620,013 is included as Appendix A of this report.

3.1 Propane-Air Torch Noise Reduction With Transverse Wires in Nozzle.

One of the means used by Rogers and Dunn [7-10] to demonstrate the principle of noise suppression pertaining to their patent, was to place a wire or ribbon across the nozzle of the propane torch tip. Although the propane torch was not specifically discussed in the patent, it was used to attract attention to the patent. Therefore, some understanding of the function of the transverse wires in reducing noise is of interest.

3.1.1 Experiments Performed

Figure 13 is a schematic of the propane torch tip showing the approximate location of the transverse rods used to reduce flame noise. The following experiments were performed.

A. Background Conditions

Sound pressure levels were obtained with (a) the torch turned off, (b) with forced air 20 cfh and (c) with forced air of 13 cfh. The spectrum levels were used to compare with levels observed when the air/fuel mixture was burning.

B. Induced Air Flow Case

1. Using a commercial BernzOmatic Jet Torch, burning propane, with no modifications of any kind, the noise level and 1/3 octave spectrum levels were measured with the propane valve fully open. The flame was photographed with a scale placed alongside to note the flame length. The flow of air induced to flow into the torch was measured.

2. Using a duplicate torch to the one used in tests described in (1), 0.0135" dia. holes were drilled to allow .010" dia. wires to be placed across the nozzle at various locations, as shown schematically in Fig. 13. With wires placed across the stream, and the propane valve fully open, noise measurements were repeated and again, photographs of the flame were taken. The air flow induced was again measured.

To obtain measurements of the induced air-flow a manifold was made to place around the torch body, surrounding the induction holes, forcing the induced air to flow through a single (0.422" dia.) hole entering the manifold. With this configuration, the induced air flow was measured with a hot wire anemometer which had been calibrated by forcing metered air through the same size inlet. The results reported herein were obtained with this maniforld around the torch body. That is;

3. With the manifold fixed around the torch body and the propane valve fully open, measurements of noise, air flow induced and flame size were made -- without transverse wires.

4. After placing transverse wires across the induction nozzle, and with the propane valve fully open, measurements of (3) were repeated.

C. Forced Air Flow

Since it was noted in experiments with the induced air flow that the transverse wires caused a reduction in induced air flow, a series of experiments was performed in which the air was forced through the torch. Thus, the air flow could be controlled independent of the presence or absence of the transverse wires in the nozzle of the torch.

With the air being forced into the manifold, and metered, the following experiments were performed.

1. Air was forced into the manifold to obtain a flame which had approximately the same appearance, size and shape (for the propane valve fully open) as the flame obtained in tests designated as B.3, with no transverse wires. Acoustic and flow rate measurements were made. The flame was photographed.

2. With the air flow and propane flow maintained as in C.1, transverse wires were inserted as shown in Fig. 13, and measurements as described in C.1 were repeated.

3. With no transverse wires present, the air flow was reduced to obtain a flame shape as noted in B.4, and the measurements of noise and air flow rate were taken and again the flame was photographed. The propane valve was fully open for this test.

3.1.2 Results of Experiments - Flame Appearance

Figure 14a is a photograph of the flame with an inch scale held alongside, for a test as described in B.3; 14b is the corresponding photograph for test B.4, with 6 transverse wires. It may be noted that the flame in Fig. 14a is much more concentrated than the one in 14b. The air flow induced by the propane jet is less when the transverse wires are present. This change in air-fuel ratio has caused the flame to lengthen and become less intense. The acoustic measurements for these two cases are discussed in section 3.1.3.

Figure 15a is a photograph of the flame with 20 cfh forced air, for the test as described in B.1. It may be noted that the flame shape and appearance is about as observed in Fig. 14a. Figure 15b is a photograph of the flame, with 20 cfh air flow and with 6 transverse wires in the torch nozzle. By comparing Figs. 15a and 15b, it can be noted that the flame appearance is not changed when the transverse wires are inserted if the air flow rate is maintained constant. When the air flow rate is reduced to 13 cfh, with no transverse wires present, and with the propane flow unchanged, the flame becomes elongated as shown by Fig. 15c; it has an appearance like that of Fig. 14b.

The same change in flame appearance can be achieved in parallel experiments, as demonstrated. where in one case the transverse wires disrupt the induction of air and in the other case the forced air is reduced. The transverse wires do not produce this flame shape change when the air flow rate is maintained by forcing it into the torch. Therefore, it can be concluded that the flame shape is changed due to the reduction of air flow induced into the torch when transverse wires are placed across the nozzle

3.1.3 Results of Experiments - Flame Noise

The noise measurements were obtained using a 1/4 inch, B&K Model 4135 microphone located 1 meter from the flame. A Model 2606 B&K microphone amplifier together with a B&K Model 1615, 1/3 octave filter set synchronized to a B&K Model 2305 sound level recorder were used to record the measured sound levels.

A. Background Noise

Figure 16 shows the background sound pressure levels without combustion in the frequency range between 200 and 20,000 Hz, which was found to be the range influenced most by combustion. Figure 16a gives the 1/3 octave sound pressure levels with no propane or air flow through the torch; in effect, the ambient noise levels. Figure 16b shows the corresponding 1/3 octave spectrum levels when 20 cfh air is forced through the torch body, (no propane), and Fig. 16c shows the levels for 13 cfh air flow, (no propane). The noise due to the air flow is slightly perceptible above the background levels, but it is not as strong a source as the flame was observed to be, as discussed next.

B. Torch Noise with Induced Air Flow

Figure 17a shows the 1/3 octave sound pressure levels for the test condition described as B.3 of Section 3.1.1, (and photograph Fig. 14a) while Fig. 17b is the corresponding plot for test condition B.4 with 6 transverse wires in the nozzle throat (also as shown in photograph of Fig. 14b). It is clear on comparing Figs 17a and 17b, that the sound pressure levels are substantially reduced in the frequency range between 300 and 5000 Hz when the wires are inserted. Between 5000 and 15,000 Hz, the case with transverse wires is perceptibly noisier. This additional noise is believed to be due to the turbulence generated by flow over the transverse wires; the overall A-weighted noise is less by about 3 dB in the case with the transverse wires but the flow of air has been reduced and the flame has become elongated due to the wires.

C. Torch Noise with Forced Air Flow

Figure 18a shows the 1/3 octave sound pressure levels for the test condition described as C.1, with 20 cfh air forced through the torch and no transverse wires in the torch. This is the same case shown photographed as Fig. 15a. This is intended to be the same combustion condition as with induced air flow

and no wires, in which case the sound pressure levels for Figs. 18a and 17a should agree. It may be observed that they do correspond within 1 dB, with those Fig 18a generally slightly higher.

Figure 18b shows the 1/3 octave sound pressure levels for the test condition described as C.2, i.e., 20 cfh forced air flow plus 6 transverse wires in the torch nozzle. Upon comparing Fig. 18a and 18b, (with the only difference being the transverse wires added for 18b) it is apparent that when the air flow is kept constant, the addition of transverse wires increases the noise, rather than decreasing it. This increase in the noise level when the wires are added is apparent over the frequency range from about 700 Hz to 15,000 Hz.

Figure 18c shows the 1/3 octave sound pressure levels for the test condition described as C.3, in which no transverse wires are present, and the air flow is regulated at 13 cfh. In this case, the sound pressure levels are reduced substantially from those measured with 20 cfh air flow and no wires, as given in Fig. 18a. The flame in this case, Fig. 15c, appeared as the flame in the induced air flow case when 6 transverse wires were inserted, Fig. 14b. The sound pressure levels are even lower for this case, Fig. 18c, than for the case shown in Fig. 17b for which the wires had reduced the induced air flow into the torch; in the case shown in Fig. 18c, the forced air flow was reduced to simulate the behavior of the wires, and the noise was reduced even more than was accomplished with transverse wires.

3.1.3 Summary of Experimental Results

Figure 19 shows a composite plot of the 1/3 octave sound pressure levels for (a) background noise, (b) noise with induced air flow and no transverse wires with the propane valve fully open and (c) with 6 transverse wires in the torch nozzle and the propane valve fully open. Clearly, the case with the transverse wires is less noisy in the frequency range between 300 and 5000 Hz than the combustion case with no wires, but more noisy between 5000 and 15,000 Hz.

Figure 20 is the composite plot of sound pressure levels for the cases with forced air flow. The levels obtained at 13 cfh airflow and no transverse wires are the lowest, followed by the levels at 20 cfh and no transverse wires. The 6 transverse wires have the effect, as pointed out earlier, of generating additional noise so that when the air flow is maintained at 20 cfh and 6 wires are inserted, the sound pressure levels are increased in every 1/3 octave band between 700 and 15,000 Hz, with little change below 700 Hz.

Finally, to check that the wires inserted across the nozzle have the effect of reducing the induced air flow, direct measurements were taken to verify this. Figure 21 shows the plot of the reduction in air flow due to the wires. It may be noted that the 6 wires reduced the air flow by about 30%, which is the approximate amount the forced air flow was reduced to simulate that aspect of the influence of the wires (20 cfh to 13 cfh).

3.1.4 Conclusion

1. The mechanism by which rods (wires) placed transversely across the supply tube of a propane torch reduce noise is as follows:

   A) The flow blockage reduces the effectiveness of the air induction by the propane jet.

   B) Less air is induced to mix with the propane in the supply tube.

   C) Since the mixture is oxygen poor, it takes a longer flame brush to burn, i.e., it requires additional surface area for oxygen to diffuse into the fuel rich jet to allow complete combustion.

   D) The resulting longer, softer flame is less noisy of itself, and since more burning is away from the torch tip, there is a weaker resonance within the supply tube.

2. The secondary effect of the transverse rods is to increase turbulence, which adds to the noise, when the flow is not allowed to be reduced by the wires.

3. The noise reduction attributed to the wires can be achieved more easily by blocking off part of the area of the holes in the torch side where the air enters, thus preventing the additional noise due to the wires.

4. Use of transverse rods, as tested in this propane torch experiment, is not a practical means of combustion noise reduction.

3.2 Further Plans

An acetylene torch was specifically mentioned in the patent [6] and is currently being studied. If it is found that the acetylene torch can be proved to function as it is intended with no degradation of performance but with a quieter flame, as suggested in the patent under study[6], then the patent may have useful ramifications for other combustors, such as in jet engines. A detailed study involving the acetylene torch with disruption rods in the flame focal point, is now in progress.

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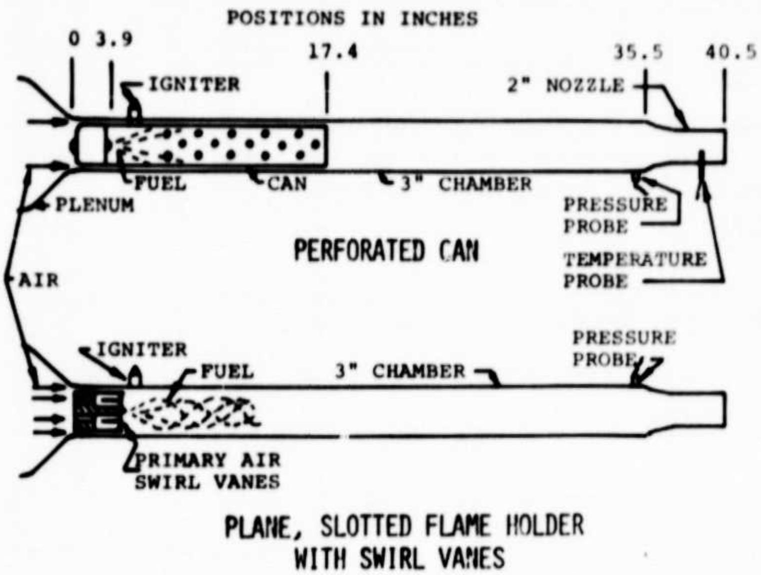


Fig. 1 Schematic of flame holding methods used in combustors to investigate effects of geometry and flame intensity on combustion roughness.

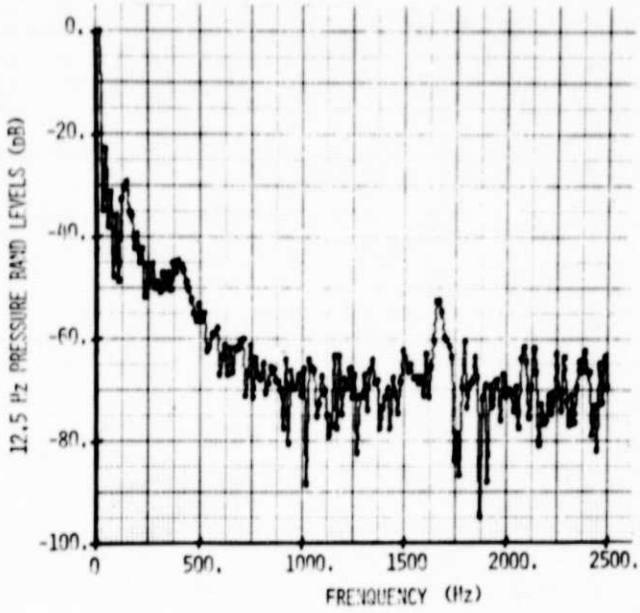


Fig. 3 Power spectral density distribution of pressure fluctuation in combustor with perforated can flame holder at a mass flow rate of 0.27 lb/sec.

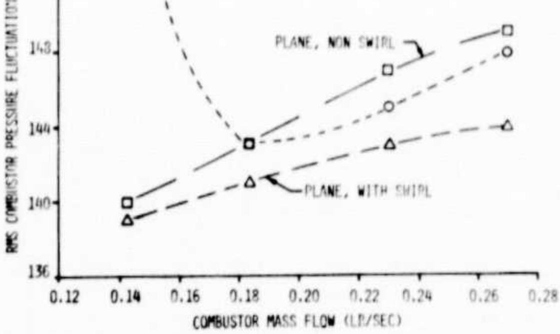


Fig. 2 Pressure fluctuation levels in combustors for a range of mass flow rates, with air/fuel ratios of 52.

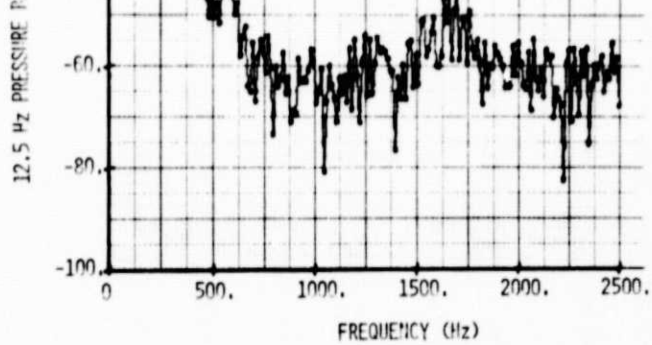


Fig. 4 Power spectral density distribution of pressure fluctuation in combustor with plane, slotted flame holder at a mass flow rate of 0.27 lb/sec.

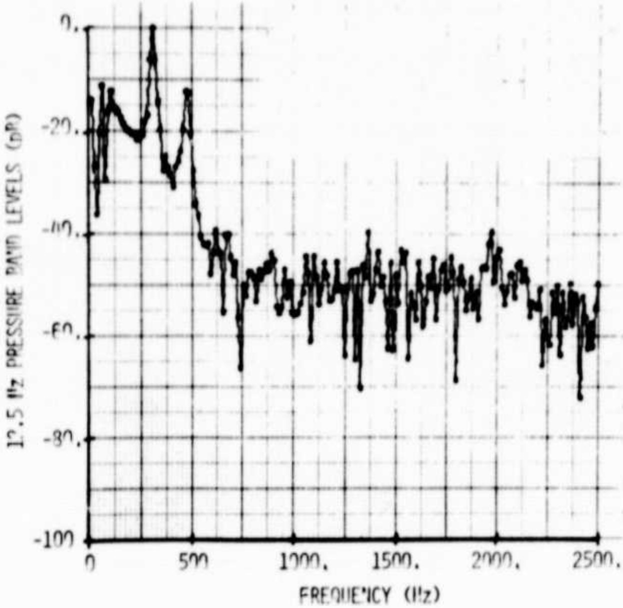


Fig. 5 Power spectral density distribution of pressure fluctuation in combustor with plane, slotted flame holder with swirl vanes, at a mass flow rate of 0.27 lb/sec.

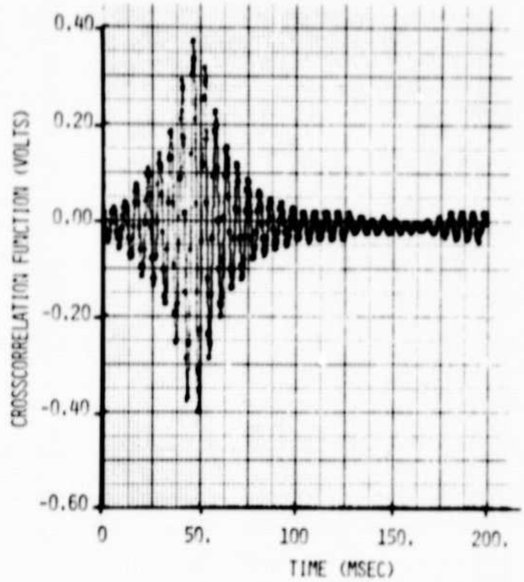


Fig. 7 Crosscorrelation of chamber pressure with far field sound at 30° to duct axis.

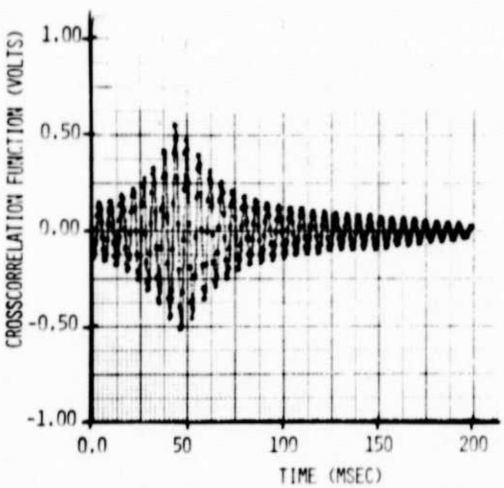


Fig. 6 Crosscorrelation of time derivative of chamber pressure with far field sound at 30° to duct axis.

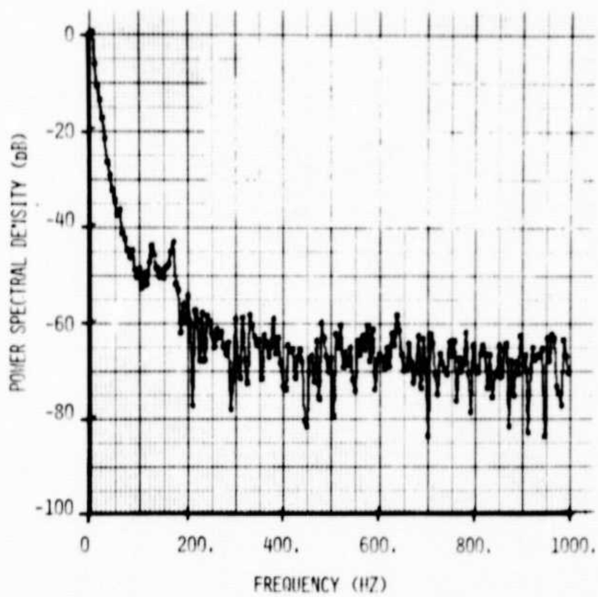


Fig. 8 Power spectral density distribution of the temperature fluctuation in the exhaust nozzle.

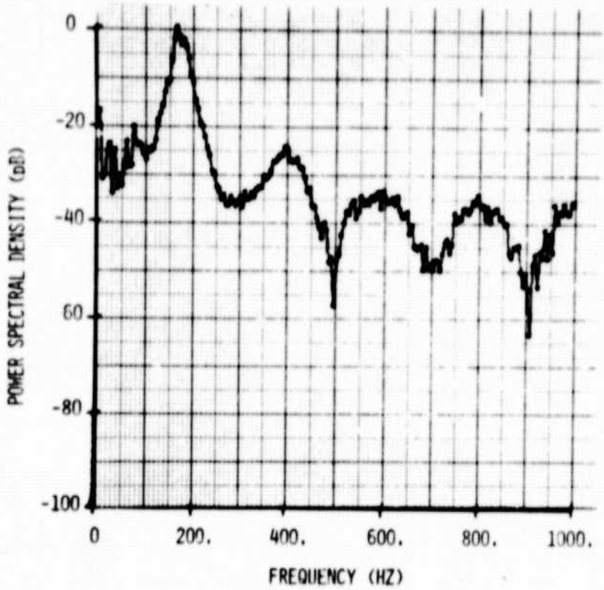


Fig. 9 Far field noise power spectral density for same case as in Fig. 8, for microphone at 60° to duct axis.

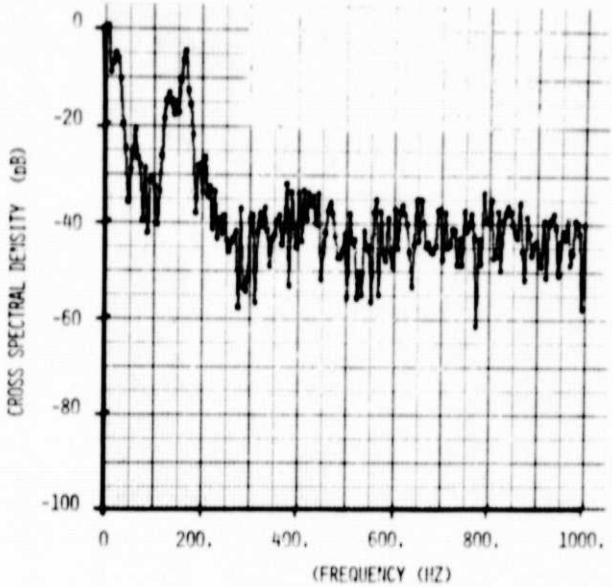


Fig. 11 Cross spectral density of nozzle temperature fluctuation and far field noise at 60° to duct axis.

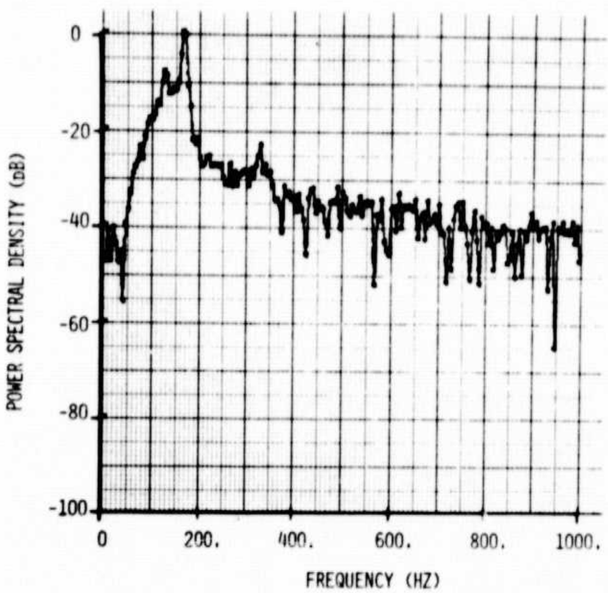


Fig. 10 Power spectral density of temperature, as Fig. 8 except that a 100 Hz highpass filter reduced the low frequency content in this record.

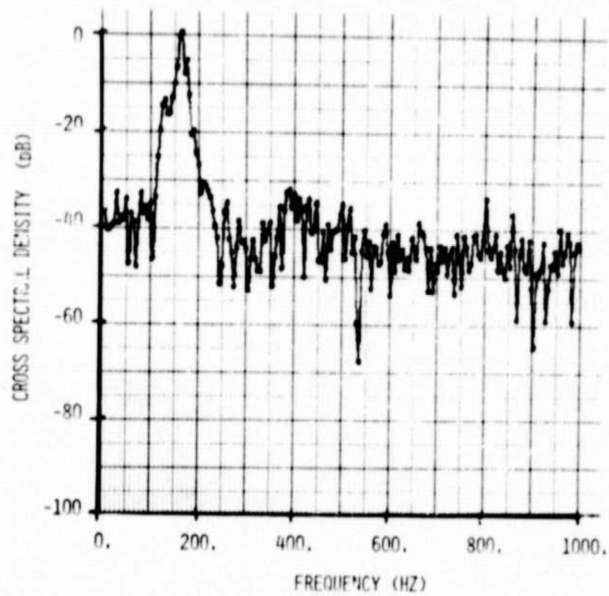


Fig. 12 Cross spectral density of nozzle temperature fluctuation and far field noise at 60° to duct axis, with 100 Hz highpass on each signal.

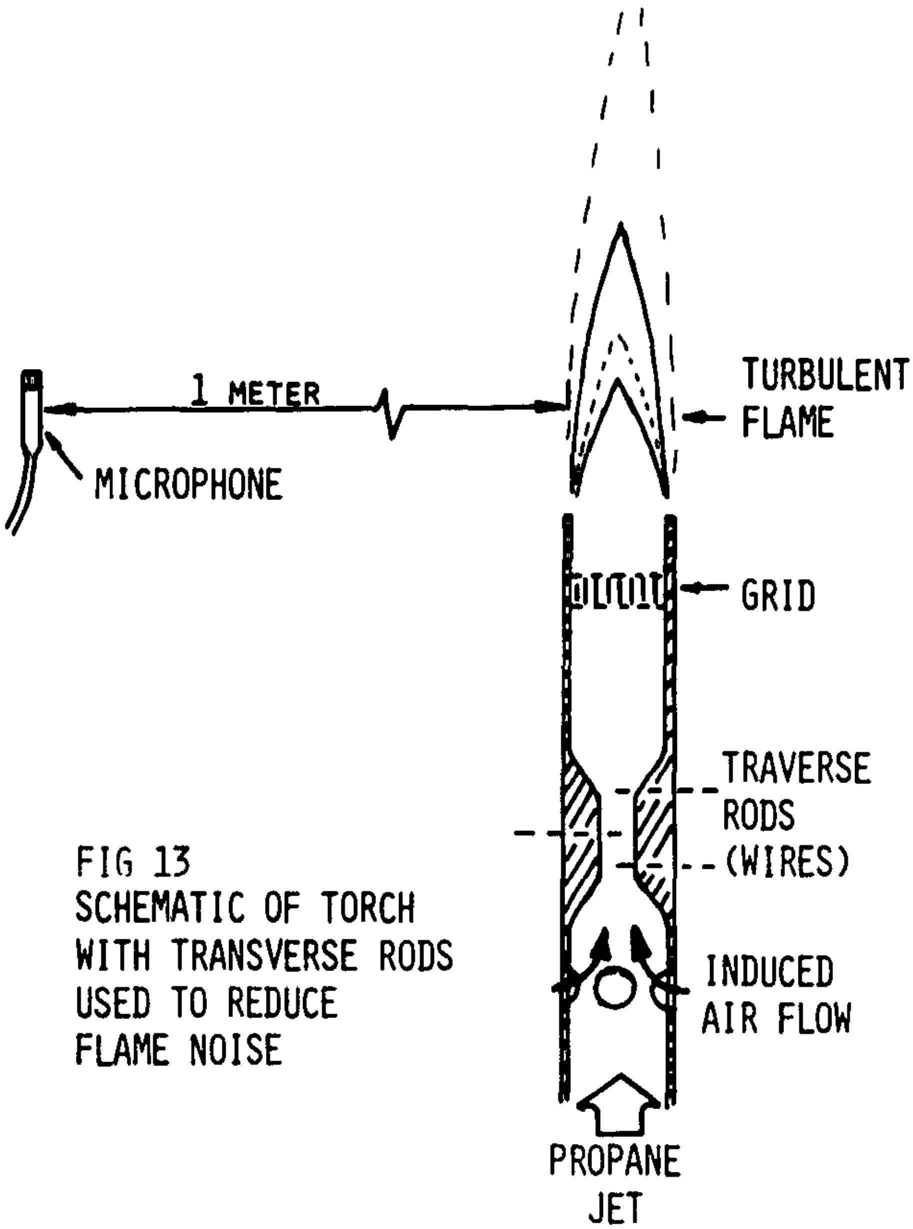
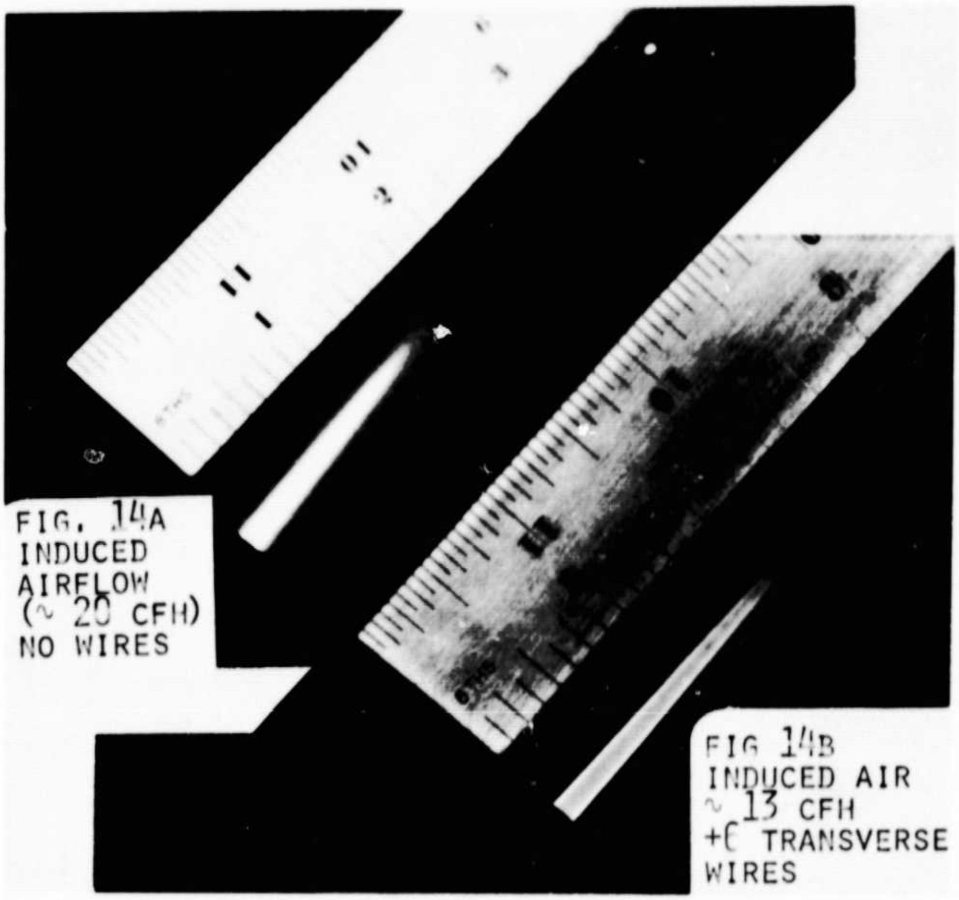
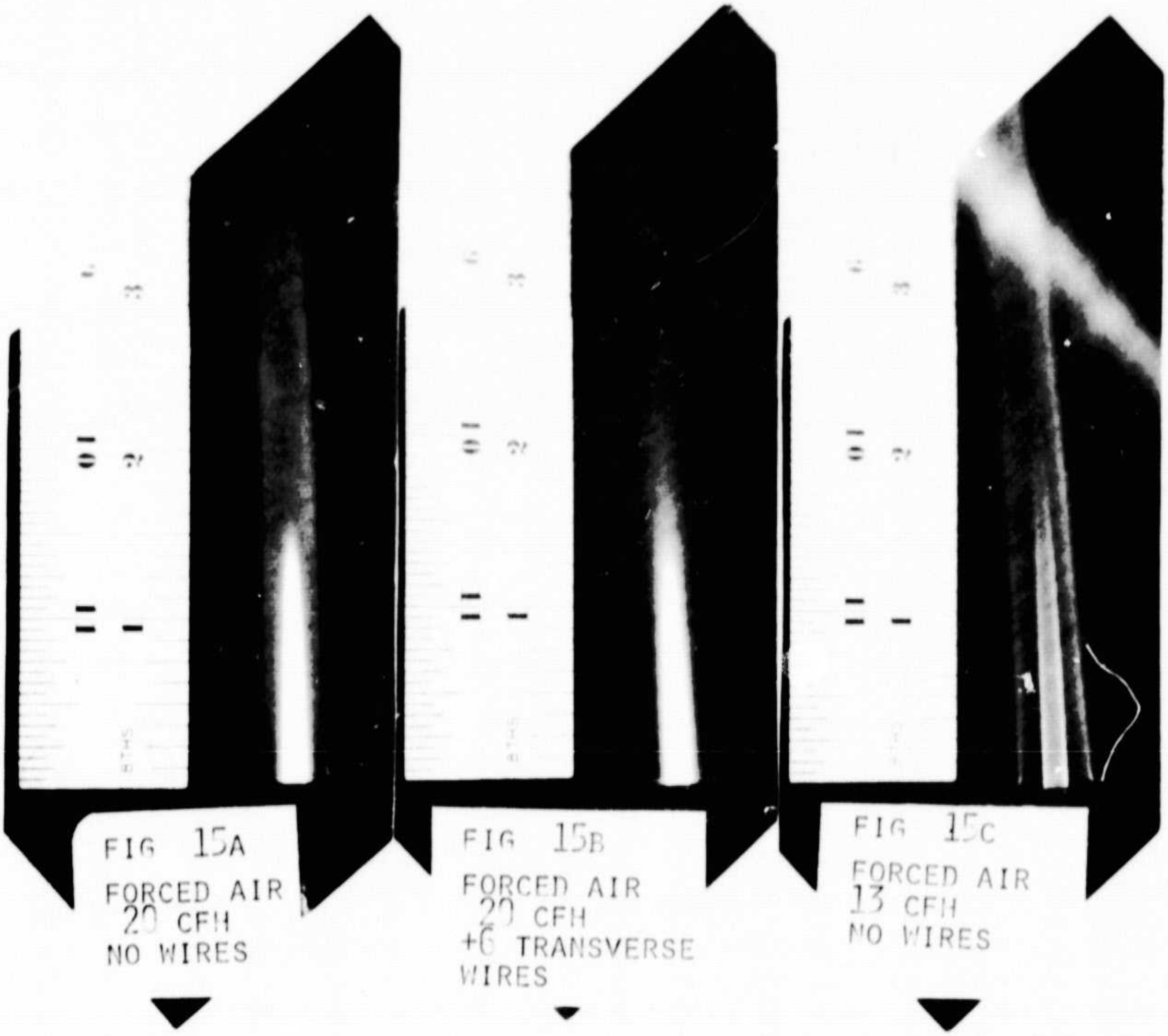


FIG 13
SCHEMATIC OF TORCH
WITH TRANSVERSE RODS
USED TO REDUCE
FLAME NOISE



THE FLAME IS ALTERED WHEN WIRES ARE INSERTED UPSTREAM. THE INDUCED AIRFLOW IS ALTERED BY THE WIRES, AND THIS APPEARS TO BE THE CAUSE OF THE ALTERED FLAME, AS MAY BE SEEN ON FIG. 15.

Fig. 14 COMPARISON OF FLAME APPEARANCE FOR INDUCED AIR FLOW, WITH AND WITHOUT TRANSVERSE WIRES.



FLAME IS APPROXIMATELY AS WITH INDUCED AIRFLOW, WITHOUT WIRES (FIG. 14a)

WHEN AIR FLOW RATE IS KEPT CONSTANT THE ADDITION OF WIRES UPSTREAM DOES NOT ALTER THE FLAME

REDUCING AIRFLOW, WITHOUT INSERTING WIRES, HAS THE SAME EFFECT ON FLAME AS WIRES HAD - WHEN WIRES REDUCED INDUCED AIRFLOW (FIG. 14b)

Fig. 15 COMPARISON OF FLAME APPEARANCE FOR FORCED AIR CASE WITH AND WITHOUT TRANSVERSE WIRES AT 20 CFH AIR FLOW RATE AND WITHOUT WIRES AT 13 CFH AIR FLOW RATE.

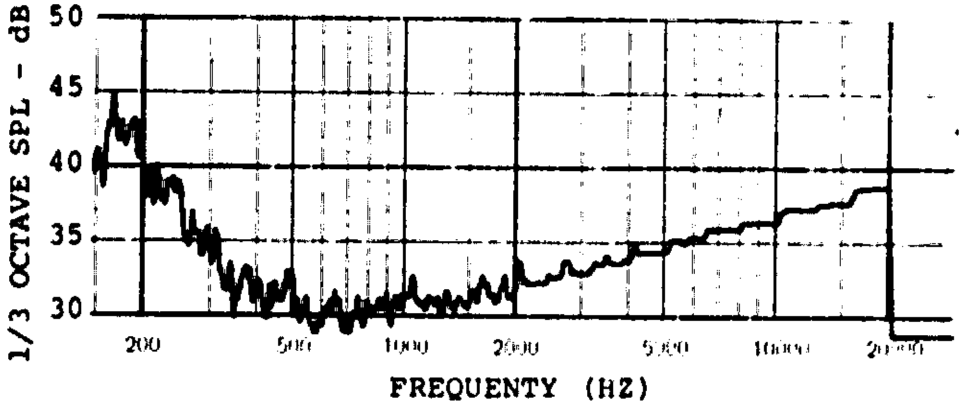


Fig. 16a BACKGROUND ROOM NOISE WITH TORCH TURNED OFF, NO GAS FLOW OR COMBUSTION.

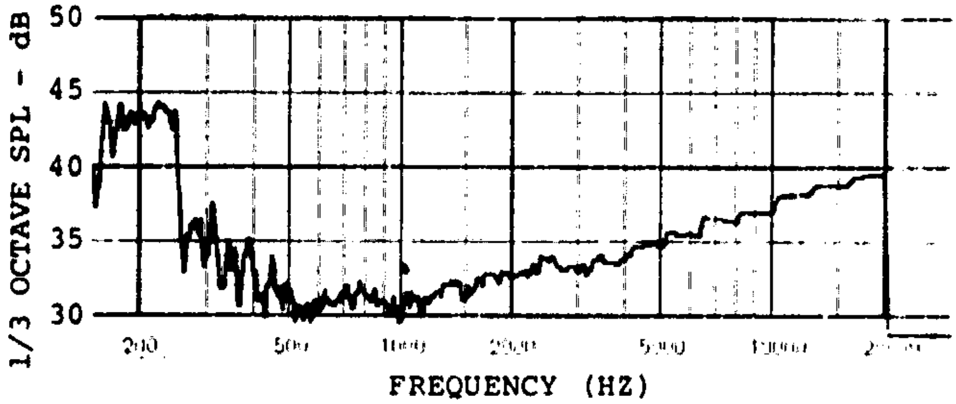


Fig. 16b BACKGROUND NOISE WITH 20 CFH AIR FLOW FORCED THROUGH THE TORCH, NO COMBUSTION.

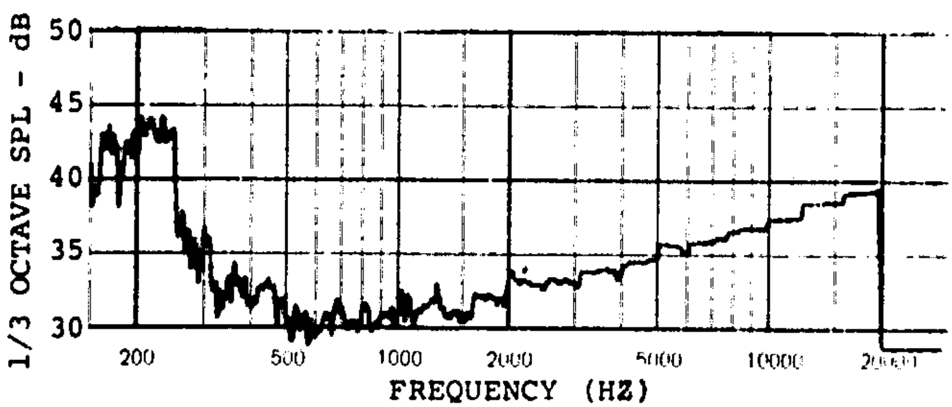


Fig. 16c BACKGROUND NOISE WITH 13 CFH AIR FLOW FORCED THROUGH THE TORCH, NO COMBUSTION.

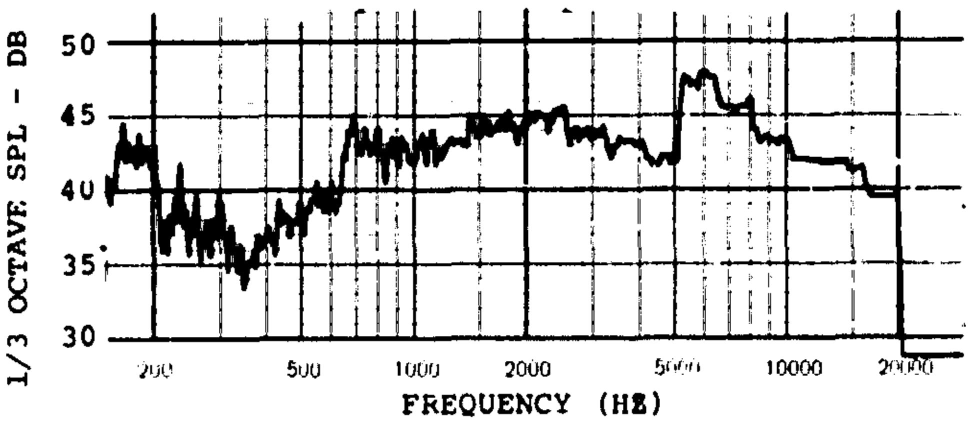


Fig. 17a NOISE FROM PROPANE TORCH WITH INDUCED AIR FLOW AND WITH NO FLOW OBSTRUCTIONS. (AIR FLOW ∿ 20 CFH) MICROPHONE: B+K MODEL 4135, 1/4" DIA., LOCATED 1 METER FROM FLAME.

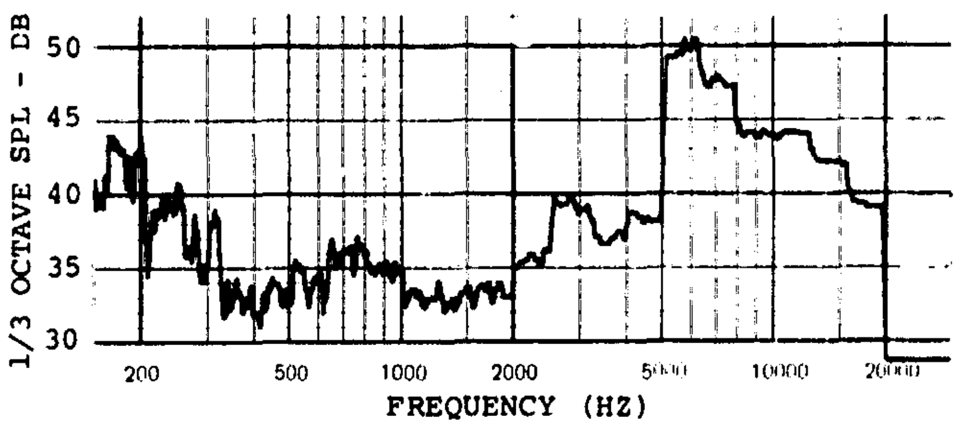


Fig. 17b NOISE FROM PROPANE TORCH WITH INDUCED AIR FLOW WITH SIX 0.010" DIA. WIRES INSERTED TRANSVERSE TO FLOW DIRECTION IN THE INDUCTION NOZZLE. (AIR FLOW ∿ 13 CFH) MICROPHONE LOCATED AS FOR FIG. 17a. NOTE THE LOWER SPL LEVELS BETWEEN 300 AND 5000 HZ, THE HIGHER LEVELS ABOVE 5000 HZ IN COMPARISON WITH FIG. 17a.

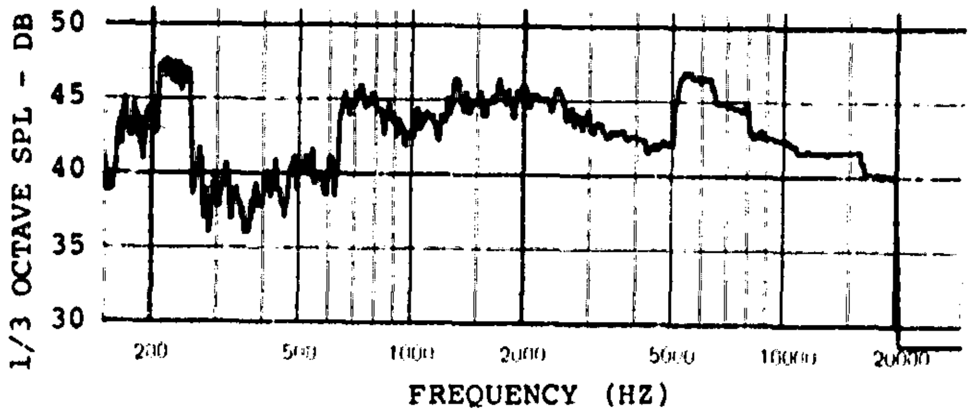


Fig. 18a NOISE FROM PROPANE TORCH WITH 20 CFH FORCED AIR FLOW, NO FLOW OBSTRUCTIONS (NO WIRES ACROSS NOZZLE). THE MICROPHONE WAS LOCATED AS FOR FIG. 17.

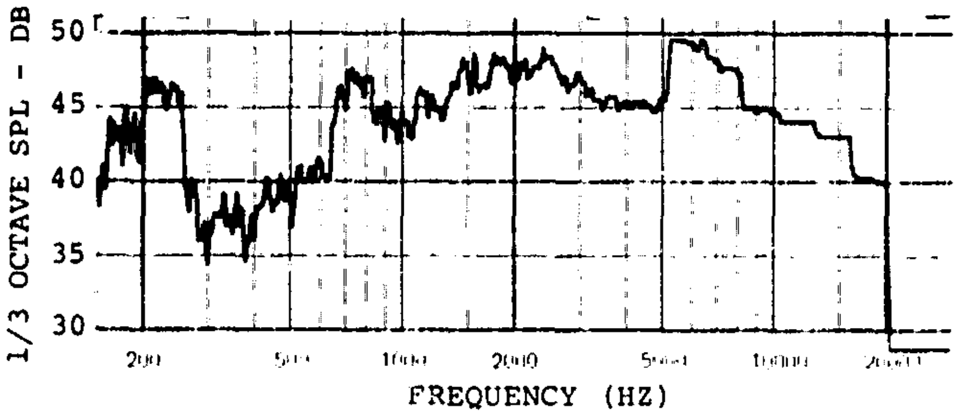


Fig. 18b NOISE FROM PROPANE TORCH WITH 20 CFH FORCED AIR FLOW WITH SIX 0.010" DIA. WIRES INSERTED TRANSVERSE TO FLOW DIRECTION IN THE INDUCTION NOZZLE. NOTE THAT THE NOISE LEVELS ARE GENERALLY HIGHER THAN IN FIG. 18a.

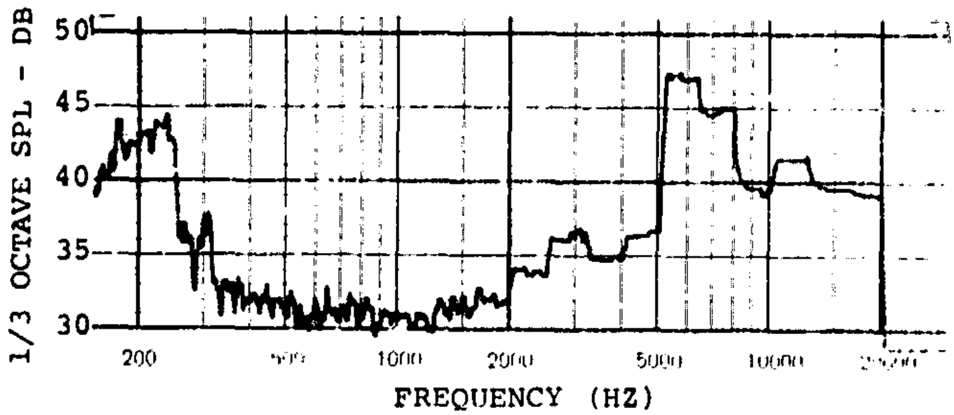


Fig. 18c NOISE FROM PROPANE TORCH WITH 13 CFH FORCED AIR FLOW WITH NO TRANSVERSE WIRES. NOTE THAT THE REDUCTION IN THE AIR FLOW CAUSED A REDUCTION IN NOISE WHILE THE ADDITION OF TRANSVERSE WIRES WITH NO REDUCTION OF AIR FLOW CAUSED AN INCREASE IN NOISE.

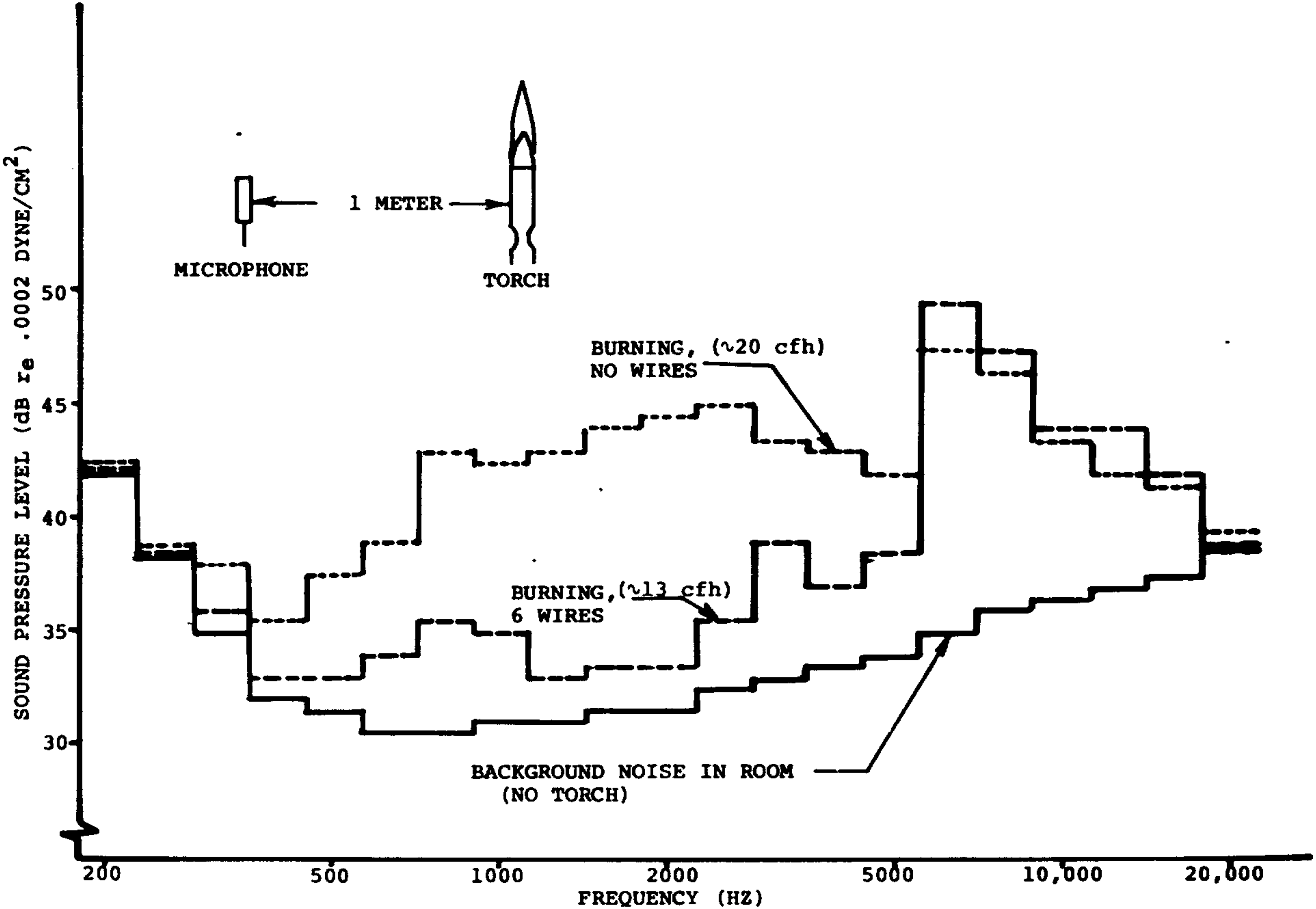


FIG. 19 1/3 OCTAVE NOISE FROM PROPANE TORCH - INDUCED AIRFLOW, SHOWING EFFECT OF TRANSVERSE WIRES IN NOZZLE UPSTREAM OF FLAME.

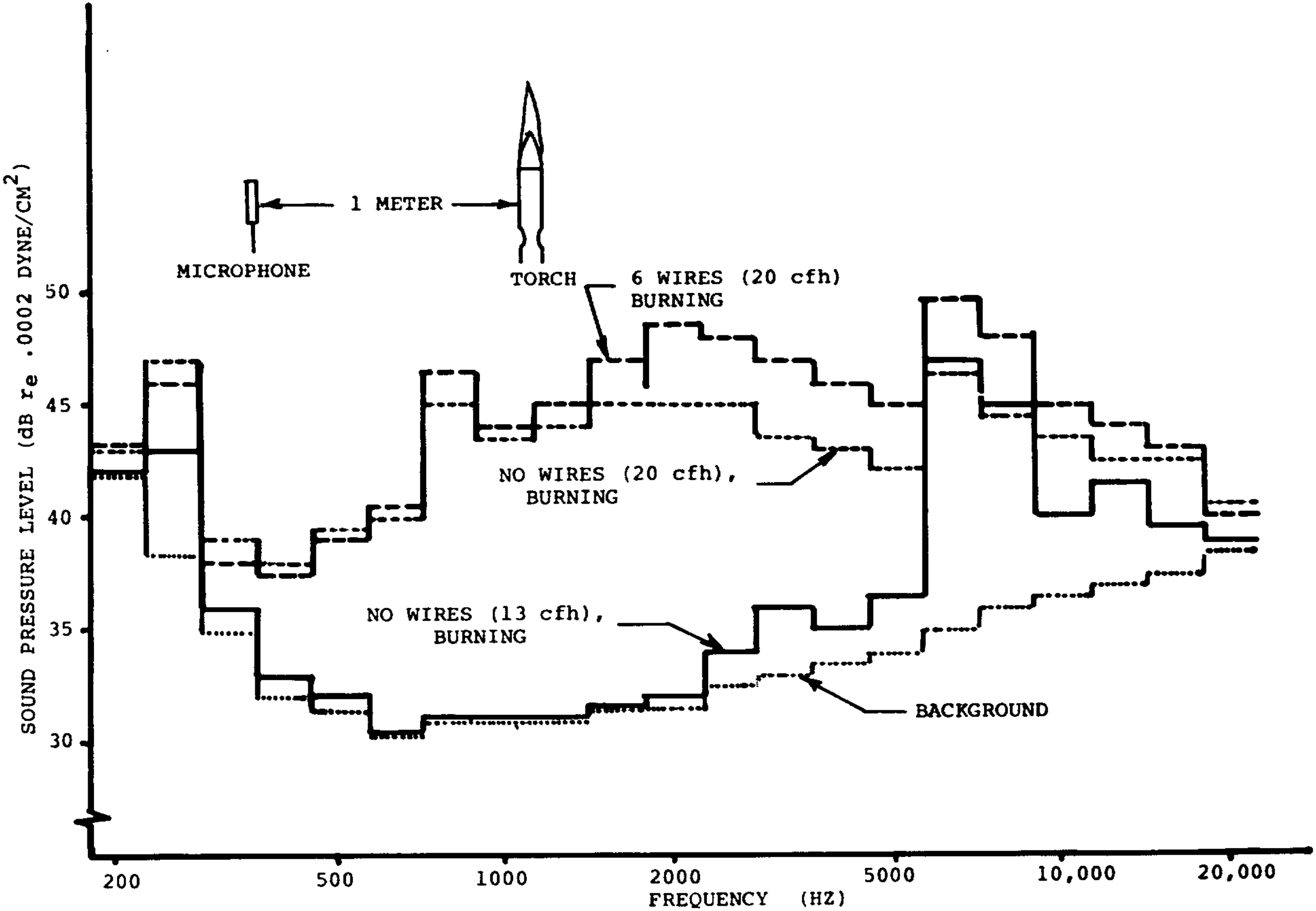


FIG. 20 1/3 OCTAVE NOISE FROM PROPANE TORCH - FORCED AIRFLOW, SHOWING EFFECT OF TRANSVERSE RODS IN NOZZLE UPSTREAM OF FLAME AND EFFECT OF REDUCED AIRFLOW.

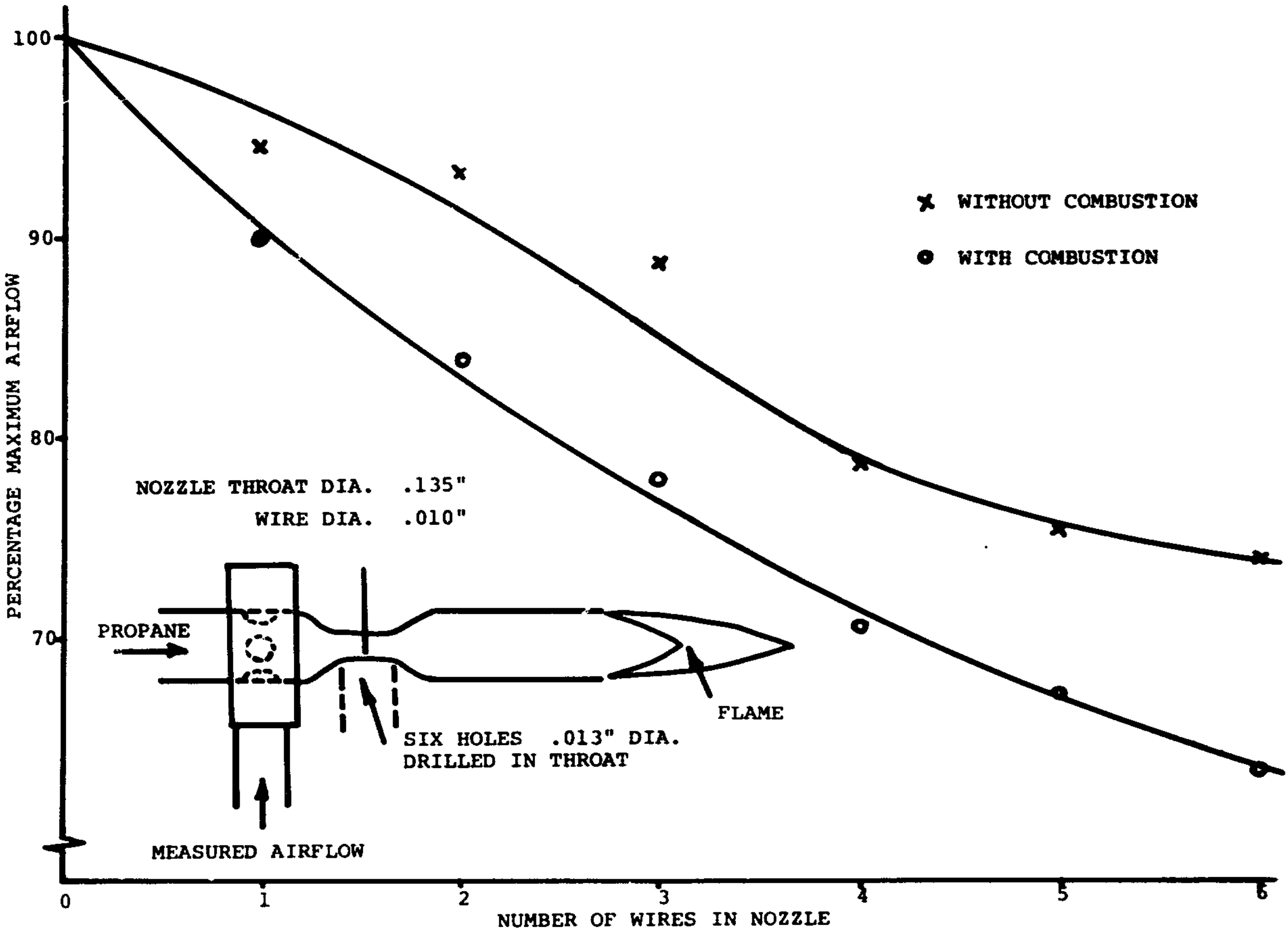


FIG. 21 MEASURED FLOW REDUCTION DUE TO WIRES FOR INDUCED AIR FLOW CONFIGURATION.

APPENDIX A

ABSTRACT OF U.S. PATENT NO. 3,620,013

for

NOISE ABATEMENT METHODS RELATING TO FLAME AND JET PRODUCTION AND ASSOCIATED APPARATUS

by

James H. Rogers and William G. Dunn

ABSTRACT OF THE DISCLOSURE

Two noise abatement techniques are employed in connection with flame generation and the production of jets. One of these techniques involves introducing a disruption rod or needle at the focal point of the parabolic section of the apex of the inner cone of a flame. The other involves using a rod or rods for cancelling the resonant node or nodes developed in a supply tube by a combustible medium passing therethrough to the flame production zone. The apparatus uses the above techniques separately or in combination and provides controls for adjusting node cancelling rods and/or disrupting rod or needle performing the aforesaid functions. The controls take into account that the nodes and focal point vary according to fuel supply rate and other factors relating to ambient and associated conditions.